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MISSILE FLAME SPECTRA

Photochemistry Laboratory, AFCRL

Analysis of the visible radiation of a missile tail flame during launch may tell us much about the fuel composition and the configuration of the missile itself. Such an analysis of the visible radiation can be made by spectrographic means from a considerable distance from the missile launch itself. This was recently reported by AFCRL scientists who have studied the visible radiation from LOX-hydrocarbon missiles by means of a slitless spectrograph. Such missiles exhibit a characteristic and reproducible pattern.

The total radiation emitted in the 4000A-6000A region varies with altitude in a manner similar to that already well established in the infrared. An altitude regime of minimum emissivity is indicated, although the absolute value of the intensity at any given altitude may differ with missile type.

The spectral distribution at a given altitude is similar for Atlas, Titan I, and Thor. At very low altitudes, there is no obvious line or band structure, but within an altitude regime identical for all three missiles several emission bands emerge above background continuum and remain prominent until burnout. These bands are attributed to two molecular species and are present in the tail flame as well as the high altitude "bloom," although available spatial resolution prevents any determination of the position with respect to the missile.

TO OUR READERS

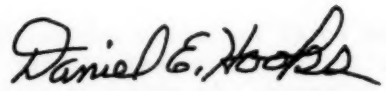
The continuing goal of the "OAR RESEARCH REVIEW" is an attempt to satisfy the information needs of both the scientist and the nonscientist decision maker, since we feel each is of importance.

It is inevitable that many decisions concerning basic research, from the budget that supports it to the manner in which it is fed into applied research and development activities, are made by people who are not scientists.

We believe that it is imperative that these people be informed about research in progress, and understand something of its potentialities. It is equally imperative that the scientist be kept up-to-date on research projects occurring within his areas of interest. Each time this publication prevents needless duplication of effort by informing a research scientist of new knowledge discovered, it will have achieved an important contribution to the conservation of the Free World's scientific resources.

Those of you among our readers who feel a need for further information about a topic covered in any issue are urged to contact the author or originating laboratory direct. Addresses for use on such occasions are shown on inside back cover of this issue.

Constructive criticism and suggestions for improvement will be most welcome, and should be directed to this headquarters, ATTN: RREI.



DANIEL E. HOOKS
Major General, USAF
Commander

UNUSUAL PROPAGATION EFFECTS

Radio Astronomy Branch, AFCRL

Some unusual and previously unobserved propagation effects have been noted by AFCRL scientists. An analysis of these effects shows that under certain conditions the gain of large aperture antennas and interferometers might be decreased by 3 db. The effects were recorded during the intense magnetic storm of 28 October 1961 using AFCRL's 84-ft. radio telescope at Sagamore Hill.

Observing the radio sources Cassopeia A and Cygnus A at that time, the lowest frequency signals at 62 mcps. showed no scintillations, while higher frequency signals at 109 and 224 mcps. showed an increasing amount of fluctuation. The normal scintillation frequency dependence is exactly the opposite. Because the refraction increases directly with wave length, the longest wave lengths usually show the greatest amplitude and scintillation.

Another strange feature of the signals from the two radio stars was, during one observation, the inversion effect was noted in signals from Cassopeia A, while Cygnus A signals showed normal scintillation.

To explain this anomaly, AFCRL scientists evaluated and correlated data from a number of sources recorded during the 28 October storm. Among these were signals recorded from the Transit IV-A satellite at 54 mcps., by the AFCRL Plum Island 19 mcps. auroral radar, from interferometers and a radiometer.

From the analysis which was recently completed, it was determined that the inversion effect is highly localized and temporal. Three factors combined to create the effect. The first was the intense magnetic storm; second, the signal source was aligned along the earth's magnetic field; and, third, there was an area of high electron density irregularity in the ionosphere.

The second of these factors explains why the inversion was noted with respect to Cassopeia A, and was not noted in observations of Cygnus A. During the particular observations, Cygnus A was transverse to the earth's magnetic field. The following explanation was given for the inversion itself: When the signal is aligned with the magnetic field and when high electron density irregularities are present, a noncoherent series of peaks and nulls exists across the 84 ft. dish; instead of receiving a single plane wave with its time-varying large peaks and nulls at the lower frequency, the nonsynchronous addition and subtraction of the many plane waves across the aperture led to a quiet signal and to a signal at times 3 db. the normal level.

the last LAUGH with laughing GAS... NITROUS OXIDE decomposition

ROBERT G. DUNN
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Laughing gas is well known for its use as an anesthetic. Present prospects are promising that this same gas eventually can be fed to advanced continuous-flow hypersonic wind tunnels to alleviate one of the most "painful" problems encountered in the advance to higher and higher Mach numbers -- the problem of obtaining high temperature air.

Atmospheric temperatures for altitudes up to 300,000 feet mostly fall in the temperature region between -110°F and +60°F. Hence, if true stagnation temperatures are to be achieved for hypersonic wind tunnels, the test medium must be expanded from quite high stagnation temperatures. For example, at a Mach number as low as 5, the required stagnation temperature is on the order of 3000°R and, at Mach 7, it is on the order of 5000°R. For the simulation of hypersonic flight conditions in the laboratory, wherein flight Mach numbers and Reynolds numbers are obtained without full flight stagnation temperatures, a relatively high stagnation temperature still must be employed to prevent condensation of the gas mixture components and the resulting adverse effects. Also, in order to obtain reasonable Reynolds numbers, stagnation pressures of several thousand pounds per square inch are necessary. For example, at realistic flight Reynolds numbers, a Mach number of approximately 14 can be obtained by employing air at 3000°R stagnation temperature and 2000 psi stagnation pressure, and a Mach number of 20 at 5000°R and 2500 psi.

The present state of the art of continuous electrical resistance heaters limits them to producing temperatures below approximately

2800°R at reasonably high Reynolds numbers. Regenerative pebble-bed heaters are considered to be suitable for producing temperatures up to approximately 4400°R under continuous-flow conditions for periods of several minutes. These temperatures are adequate for the generation of liquefaction-free flows of air at Mach numbers as high as 14 and 18, respectively. Although much useful aerodynamic testing can be done with this operational capability, still higher stagnation temperatures are definitely required. The general problem is to find a means of heating a gas, preferably air, to temperatures sufficiently high (500°R or higher) to allow the study of real gas effects, and/or to permit expansion to Mach numbers higher than 18; also, to provide such air in quantities adequate for wind tunnel testing of several minutes duration.

Although extremely important in the simulation of hypersonic flight conditions, a satisfactory method of producing contaminate-free high enthalpy air for continuous-flow wind tunnels operating at stagnation temperatures above 4400°R has not yet been devised. Techniques currently under study for this purpose include mechanical and magnetohydrodynamic accelerator techniques and chemical reaction techniques. The first two of these are viewed as relatively longer range solutions of the problem, and offer prospects of the highest ultimate Mach numbers and/or stagnation temperatures. The chemical reaction technique may provide the more immediate solution to the problem promising longer running times and higher stagnation temperatures in the neighborhood of 4400°R, and possibly several thousand degrees higher.

Several chemical heating methods have been employed to produce high-temperature streams for aerodynamic test purposes, since high temperatures are easily achieved by this means. The exhaust products from combustion heaters have been used in this manner; the products obtained from the combustion of high energy rocket fuels have been used in some cases. Also, the hot gaseous products from the thermal decomposition of an endothermic compound have been considered as a test medium. However, despite the extreme simplicity of this technique, these chemically heated streams have had only limited use in the past, since the thermodynamic and other important properties of the hot combustion gases are in most cases different from those of hot uncontaminated air.

Chemical heating techniques based on the exothermic decomposition of nitrous oxide have been under investigation for some time. The compound nitrous oxide (N_2O) contains only nitrogen and oxygen, and decomposes in a highly exothermic chemical reaction, as follows:

$$2\ N_2O \rightarrow 2\ N_2 + O_2 + \text{Heat}$$

One technique involving the thermal decomposition of nitrous oxide

is based on the concept of using an electrical resistance heater to raise the temperature of the nitrous oxide to a level near 2500°R. Upon decomposition of the gas, the heat released in the process would increase the temperature of the gaseous products to an estimated temperature in the neighborhood of 5000-6000°R, and would produce a gas closely resembling air but rich in oxygen. By the addition of the proper amounts of nitrogen (and argon), which can be heated independently by known inert-gas heating techniques to temperatures near 5000°R, a stream of very high temperature gas having composition and properties identical to those of air could be produced. A question of major importance in the process of initially heating the nitrous oxide is that of estimating the reaction rate for the decomposition, since this establishes the minimum permissible flow rate of the gas through the heater.

Hence, reaction kinetics data under conditions suitable for wind tunnel operation are required. Although the decomposition of nitrous oxide has been studied extensively by several investigators, most of the studies were limited to low pressures and temperatures. In exceptional cases, the range of investigation was extended to temperatures as high as 1800°R and pressures as high as 590 psi. It appears certain that no previous measurements of the decomposition rate for nitrous oxide have been made at temperatures above 1800°R.

An alternate technique involving the thermal decomposition of nitrous oxide would provide a means of boosting air temperatures from the neighborhood of 2500°R to temperatures between 3500°R and 5000°R. In this method, moderate amounts of nitrous oxide would be injected into an air stream heated by existing techniques to 2500°R. The heat release from the N_2O decomposition would provide the temperature boost, and the product would be made identical to air by the addition of the required amount of nitrogen (and argon).

The detonation and explosive characteristics of nitrous oxide and the chemical kinetics of its decomposition are being investigated by Dr. Rudolph Edse and Mr. Loren Bollinger, under contract at the Ohio State University, in the pressure and temperature ranges of interest for application to advanced continuous hypersonic wind tunnels. This study also includes mixtures of nitrous oxide with nitrogen and air. Since nitrous oxide decomposes on a self-sustaining basis if sufficient heat is added, the possibility exists that it will detonate under certain conditions. For wind tunnel usage, all such conditions must be avoided. The present state of the art is such that one cannot predict theoretically with any degree of reliability whether nitrous oxide will detonate under specific operating conditions. Part of the OSU investigation involves determination of the detonability of nitrous oxide under conditions that simulate some of the tunnel operating conditions. In order to elucidate further the decomposition reaction mechanism of nitrous

oxide, the OSU studies also include experiments to determine the explosion limits of the gas and a study of the kinetics of the system to ascertain the reaction rates.

Under the OSU contract, the detonability characteristics of nitrous oxide and its mixtures with nitrogen and air are being investigated at initial pressures from atmospheric to 3000 psi, and initial temperatures from 520°R to 1800°R or to the ignition temperature. The mechanism and rates of reaction are being determined at initial pressures from atmospheric to 3000 psi and initial temperatures from 1800°R to 3000°R, and possibly at higher temperatures. Explosion limits are being established as a function of temperature and pressure within these ranges.

In summarizing the results obtained at OSU to date, it can be stated that it is difficult to initiate detonation in nitrous oxide under the experimental conditions investigated (pressures to 500 psi at temperatures to 950°R; pressures to 2200 psi at temperatures to 635°R). It seems reasonable to assume, upon extension of the investigation to more extreme values of initial pressure and temperature, eventually certain conditions will be attained where a self-sustaining detonation wave will form. A definite explosion limit curve has been established for pure gaseous nitrous oxide at temperatures up to 1855°R and pressures up to 100 psi. Experiments have indicated that no explosions occur in the mixture N_2O + 0.88 N_2 or in the mixture N_2O + 0.88 N_2 + 0.5 AIR at pressures up to 3000 psi and temperatures up to 1800°R. For the mixture N_2O + 0.25 AIR reactions occur under some conditions at pressures up to 800 psi and temperatures up to 1600°R. It is expected that, as the experimental pressures and temperatures are pushed higher, an explosion limit curve will be reached and established for this mixture. The reaction kinetics of nitrous oxide has been studied in a qualitative way at pressures up to 1920 psi and at temperatures in some cases up to 2900°R.

In the near future, the detonability and explosion limit studies will be extended to the desired limits of 3000 psi initial pressure and 1800°R initial temperature. Also, the kinetics investigation will be extended to 3000 psi and 3000°R, and will include quantitative determination of reaction rates and degree of completion of the reactions, particularly the extent of disappearance of the nitrous oxide. Additives will be considered to determine the extent to which the nitrous oxide decomposition rate can be controlled. "Boost heating" of an air stream, by the injection of small quantities of nitrous oxide, or nitrous oxide-nitrogen mixtures, into hot air, will also be investigated.

Nitrous oxide may well have the last laugh in the search for high temperature air.

CHEMICAL SUMS OF SOME CHEMICALS

BRANDES H. SMITH, 1st Lt, USAF

Directorate of Chemical Sciences, AFOSR

Research on high energy fuels for supersonic aircraft has been stimulated by the desire to increase range and other in-flight performance. Some chemical compounds which offer potential improvements in these areas are the derivatives of boron. As yet, we do not know the complete story and value of these substances. But, through critical and probing basic studies, more and more practical uses and limitations of them are being unearthed, as the following inductive study shows.

The old saying that the whole is equal to the sum of its parts may not ALWAYS be true but, for the vast majority of cases, it is indeed so. However, sometimes we are unable to see the "whole" as it exists, and must resort to the summation of its parts for a fuller understanding. This frequently is the case in chemical experimentation. Thus, the chemist undertakes his own peculiar form of summation. He carefully examines the parts and fragments of the molecule, and from them deduces the whole and gains added knowledge of it.

One important instrument for helping deduce the whole from its parts is the mass spectrometer which fragments a molecule by electron bombardment.

The ions produced by the electron bombardment arise by a process such as

$$A + e \longrightarrow A^+ + 2e$$

The yield of the ion A^+ is studied as a function of the energy of the bombarding electron e. The energy, or potential, at which the ion first appears is called the appearance potential. In the above process, the appearance potential is just the ionization potential of A. If, however, we are considering a slightly more complex process

$$A_2 + e \longrightarrow A + A^+ + 2e$$

then the appearance potential is the energy needed to fragment A_2 to 2A and then to ionize one A to A^+. All the above is based on the assumption that the ions and fragments are in their lowest

energy states. If they are not, additional considerations must be made. If the appearance potentials and fragmentation reactions are known, other information such as ionization potential, bond energies and substituent effects can be determined.

Dr. Walter S. Koski, of Johns Hopkins University, has used this mass-spectrometric technique to determine the average energy of the boron-iodine bond in boron tri-iodide. One of the processes occurring in the mass spectrometer is

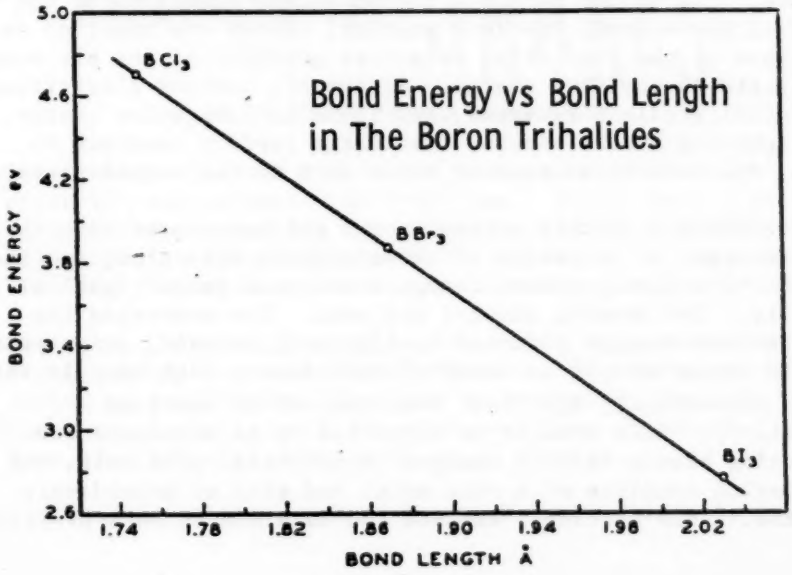
$$BI_3 + e \longrightarrow B^+ + 3I + 2e$$

If X is the appearance potential of the B^+ ion, Y is the boron-iodine bond energy and Z the ionization potential of the boron atom then

$$X = 3Y + Z$$

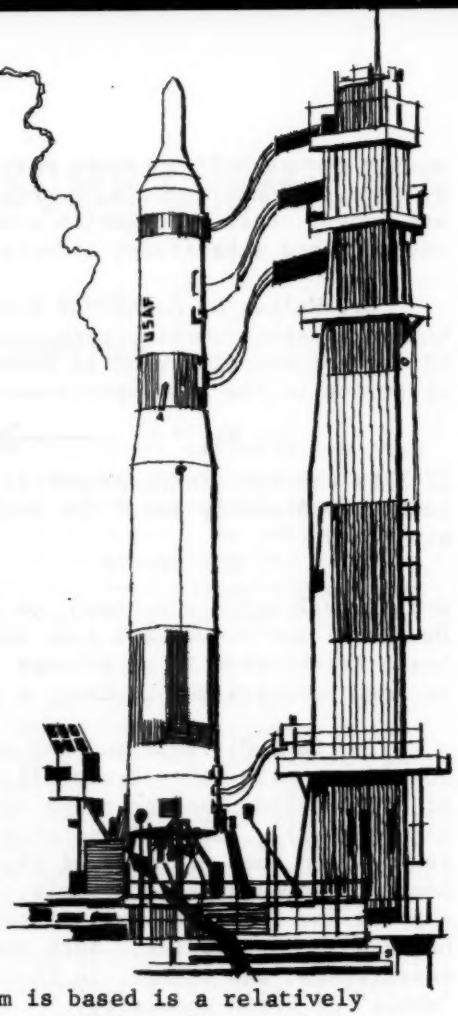
and since X and Z are known, an average Y can be calculated readily. Dr. Koski and co-workers also did this for boron tribromide and boron trichloride in an attempt to calculate a self-consistent set of bond energies and ionization potentials for the boron trihalides.

In the B-Cl, B-Br and B-I series, a regularity in potential, consistent with other Group III halides, was noted. Thus, a plot of boron-halide bond energies versus bond lengths gave a straight line (Fig I). This relationship establishes confidence in the bond lengths and bond energies of BI_3 as calculated from the measurements of appearance potentials. Also, this procedure provides added support for the technique, in general, and the data on the boron halides, in particular. Such aids are important to Air Force Researchers, and others, in their continuing quest to unravel the "whole" of boron chemistry.



lightning alert system

Meteorological Development Laboratory, AFCRL



A missile standing high above surrounding terrain on a launch pad is a highly effective lightning rod. If struck by lightning, electrical components could be destroyed. When the fueling operation begins, we have a potentially dangerous situation. This danger has led AFCRL, together with its contractor, A. D. Little, to develop a system that will alert missile crews to atmospheric conditions likely to produce lightning strokes. The system will soon be installed at Patrick AFB, Florida.

The technique on which the system is based is a relatively simple one. The system measures the potential gradients of the surrounding atmosphere. In fair weather, before the onset of rain, measurements of the electrical potential gradient of the air overhead indicate a positive charge. As the air becomes electrified, the potential gradient reverses, and there is a negative charge. When a lightning stroke occurs, the charge rapidly reverses to positive, followed by an equally rapid drop to the negative state.

The AFCRL-A.D. Little system is one which measures both the rate of increase in intensity of these effects with time, and the occurrence of sudden gradient change above some preset level of sensitivity. Two sensing devices are used. For measuring the sudden gradient changes produced by lightning strokes, an antenna having the appearance of an inverted bowl atop a high mast is used (in early experiments, this bowl consisted of an aluminum "snowcoaster"). This antenna is supported by an insulated rod. For measuring slowly varying changes in potential gradients, the sensing device consists of a thin metal rod with an exceedingly sharp point. This vertical, exposed rod is elevated to a position

well above surrounding obstructions. Electric current (in the microampere range) flows into the atmosphere from the point. The amount of flow (which can be measured) is set by the electric potential gradient of the atmosphere. At its most sensitive level, the system can detect a lightning discharge at a maximum range out to 100 km.

Distances and trends of a storm are determined by threshold sensitivity settings. There are three of these settings, with the degree of sensitivity decreasing by factors of 10 -- that is, if the most sensitive setting is one, the next most sensitive level is one tenth as sensitive, and the least sensitive level is one hundredth as sensitive. Each of these threshold settings, in turn, has three channels. Sensitivity levels of each of the three channels within each of the three threshold levels are also separated by factors of ten.

The operator is alerted by warning lights on each channel, by an Esterline-Angus recorder for observing trends, and by resettable counters to indicate the number of times each channel has been activated.

It is easy to detect electrical disturbances with a simple loop antenna and radio receiver. But a warning system based on the detection of the electromagnetic signals generated by lightning strokes cannot provide the fine grain features of atmospheric electricity that are possible through measurements of electric potential gradients which provide the basis for this system.

STEADYING THE SHAKES

MILTON ROGERS, Mechanics Division, AFOSR

The problem of stall flutter of isolated airfoils first received some attention approximately 20 years ago. Since then, there have been various theoretical and experimental programs aimed at either predicting flutter speeds in the stall region, or at obtaining an understanding of the character of the unsteady aerodynamics involved.

The term, "flutter," as it is ordinarily used, refers to classical (e.g., bending-torsion type) flutter. If, during part or all of a period of oscillation, the flow is separated, then the flutter exhibits several characteristics different from classical flutter. This type of flutter is defined as stall flutter.

The failure of the original Tacoma Narrows Bridge is generally

believed to have been due to stall flutter. This bridge was destroyed in 1941 at a wind speed of 42 MPH, although it was designed to resist a steady maximum wind speed of 100 MPH. Stall flutter is also a serious aeroelastic instability for rotating machinery, such as, propellers, turbine blades and compressors, which sometimes have to operate at angles of attack close to the static stalling angle of the blades. Airplane wings and tails have not yet generally suffered from stall flutter. However, some recent design trends have made wing stall flutter a serious consideration in the design of high-speed aircraft.

In general, as the mean angle of attack is increased through the static stall region, the following characteristics may be observed:

(a) The torsional motion predominates; i.e., in classical flutter, the torsional strain and bending strain are of the same order of magnitude but, in stall flutter, the amplitude of the bending oscillation becomes negligibly small in comparison to the torsional oscillations, although the axis of rotation is, in general, not the elastic axis.

(b) The critical flutter speed drops severely from the classical flutter speed.

(c) The flutter frequency rises slowly toward the natural torsional oscillation frequency of the blade or wing in a vacuum.

(d) Usually the critical flutter speed reaches a minimum and rises again as the blade or wing becomes completely stalled.

(e) There is a large phase shift at the transition from classical flutter to stall flutter.

(f) Variations of the structural properties of the airfoils have very different effects on stall flutter compared to classical flutter.

By and large, because of the mathematical difficulties involved in the aerodynamics of unsteady stalled flow, most of the theoretical efforts to date for predicting flutter speeds in the stall region have been limited to modifications of classical theory. Some efforts, however, have been made to study realistically the aerodynamic load on an airfoil oscillating about a large initial angle of attack. However, these theories assume the lift curve to be linear which

restricts their applicability to a very small displacement from the mean angle of attack.

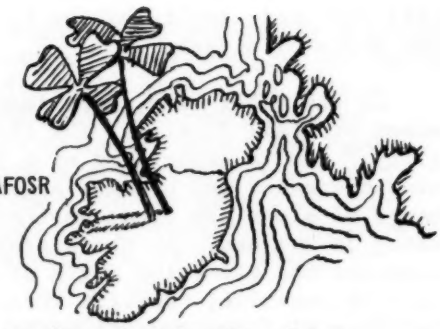
On the other hand, experimental work has shown three possible causes of stall flutter. The first cause is termed "static instability," and is associated with the fact that the slope of the lift curve decreases and becomes negative near the stall point. This change of slope can cause an instability, explained by J. P. Den Hartog as follows: As the airfoil moves upward, the resultant motion decreases the effective angle of attack. If the slope of the lift curve is negative, the lift force will increase, and the vibrations therefore will continue to build up. This explanation using the static lift curve is, of course, not strictly correct for the conditions of flutter, because the dynamic lift curve is different from the static lift curve.

The second possible cause for stall flutter is the excitation of the airfoil by a system of Karman vortices shed in the wake. Karman vortices produce an excitation with a frequency directly proportional to the air velocity, and could cause an instability of the airfoil.

The third cause was initially investigated by H. Studer who carried out the first important experimental work. Studer's results show that, in a stroke of increasing amplitude, separation is delayed to an angle of attack appreciably greater than that for a stationary airfoil. On the return movement, re-establishment of a smooth flow is also delayed. Studer called this "aerodynamic hysteresis," and concluded that it is the basic cause of stall flutter, since the oscillation is aerodynamically unstable with respect to pitching if the gain of energy during each cycle is positive.

As part of a continuing study of unsteady flows, sponsored by AFOSR at Cornell University (AF 49(638)-544), Mr. J. M. Ii, working under Professor Wm. R. Sears, has developed an analytic approach for the study of stall flutter with one degree of freedom in torsion. As presented in AFOSR TN 899, Mr. Ii's approach combines the first and second causes of stall flutter, and incorporates the nonlinear behavior of the "aerodynamic hysteresis" by expansion of the static moment curve in a Taylor series about the mean incidence angle of attack which is usually high for stall flutter. The influence of the Karman vortices shed from the given airfoil is represented in general harmonic form. The response of the system, after a quasi-steady state is reached, is found by application of the method of Kryloff and Bogoliuboff. The stability problem and the distinctive nonlinear characteristics, such as the limit cycle and jump phenomena, are clarified. An illustrative example presented in the report, together with a semi-empirical comparison with experimental results, shows considerable promise of the method which may warrant further refinement.

A JEWEL FROM THE EMERALD ISLE



B. R. AGINS, Captain, USAF, Applied Mathematics Division, AFOSR

An important problem in modern aerodynamics is the plate problem which describes the reaction in plates to various applied forces.

Working under an AFOSR contract, Professor P. M. Quinlan, University College, Cork, Ireland, has developed a new method capable of solving plate problems for rectangular plates under all systems of transverse loadings -- concentrated line loads, distributed loads, concentrated and distributed moments, and for all boundary conditions.

Extensive use is made of two step functions, which change from + 1 to - 1 at certain points, to enable all cases to be presented by a single formula. This is especially useful when integrating the concentrated load case to obtain line and distributed loadings. The tensor-like qualities of these functions are shown in a striking way: Thirty-two different cases for the moment at a point in a skew-plate with fixed edges are expressed in a single formula.

The calculus of two step functions was fully developed, leading to easily applied operators for expressing deflections, moments, shears, etc., in terms of certain functions. Doubly infinite Fourier series are replaced by finite summations.

The power and scope of this method were demonstrated in three examples worked by Professor Quinlan. The most difficult one involved the calculation of the shear at a point in a plate due to uniform loading on a rectangle with sides parallel to the plate edges.

Methods were also developed for solving similar problems for orthotropic plates, for plates on elastic foundations, and for plates subject to forces in the plane of the plate.

The methods and tables developed are, in general, applicable to all boundary value problems which can be solved by double Fourier series methods.

GPO 927868

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